





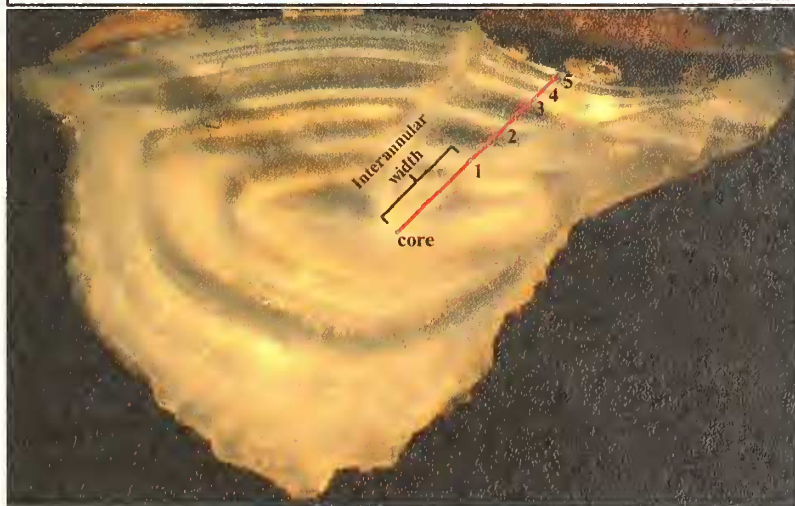
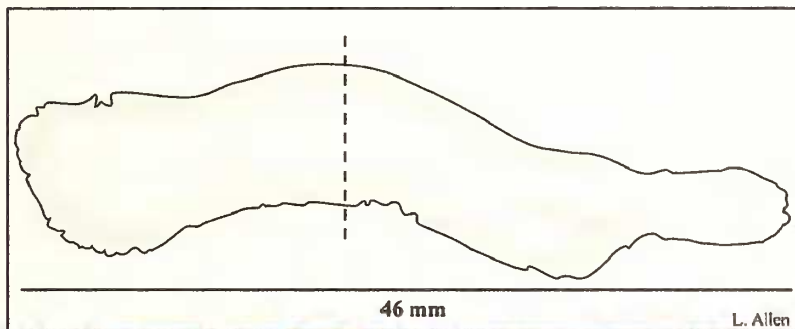
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## Growth, Development, and Reproduction in Gulf Corvina (*Cynoscion othonopterus*)

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**Abstract.**—Gulf corvina, *Cynoscion othonopterus*, is a vital component of commercial fisheries in the northern Gulf of California, but a lack of information on life history parameters have thus far prevented a comprehensive stock assessment. In this project, 530 specimens of Gulf corvina were collected from commercial gill net fisheries in the Colorado River Delta region in Sonora, Mexico, to characterize population structure, age and growth patterns, age and size at sexual maturity and batch fecundity. Fish ranged from 145 mm to 1013 mm in total length and from 1 to 8 years of age. Von Bertalanffy growth model parameters were:  $L_{\infty}$  = 1006 mm,  $k$  = 0.255/yr,  $t_0$  = 0.616 years. Growth rates of Gulf corvina did not differ significantly between sexes, although females were predicted to reach a larger asymptotic length. Mean size ( $L_{m50}$ ) and age ( $A_{m50}$ ) at sexual maturity from histological analyses of gonad tissues was 294.7 mm and 2.3 years for females and 267.5 mm and 2.0 years for males. Maturity estimates from otolith analyses did not differ between sexes and were similar to maturity estimates derived from gonadal histology, indicating that energy allocation shifts from growth to maturation and reproduction after year two. Batch fecundity ranged from 240,394 to 1,219,342 eggs with a mean of 684,293 eggs per spawn, and was correlated to both total length and gonad-free body weight. The distribution of oocyte diameters and oocyte stages indicate that Gulf corvina is a multiple batch spawner with asynchronous oocyte development and indeterminate annual fecundity.

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### Introduction

The Gulf corvina, *Cynoscion othonopterus* (Jordan & Gilbert 1882), is a member of the family Sciaenidae and is endemic to the northern Gulf of California, the region north of latitude 28°61' S (Robertson and Allen 2008). Adult Gulf corvina are carnivorous, feeding on benthic crustaceans, mollusks, and schooling fishes such as anchovies and sardines (Román-Rodríguez 2000). Spawning is restricted to the upper reach of the Gulf of California and is correlated to tidal patterns: adults migrate to the Colorado River Delta during the weeks preceding the new and full moons of March and April and form massive spawning aggregations in the estuary (Erisman et al. 2012). The spawning season

is tightly linked to the timing of historic spring floods of the Colorado River, which created an extensive brackish nursery habitat for Gulf corvina and other fish (Rowell et al. 2005, 2008).

The commercial fishery for Gulf corvina is economically significant in the northern Gulf of California (Paredes et al. 2010; Rodríguez-Quiroz et al. 2010) and has a direct conservation impact, because it is centered inside the upper Gulf of California and Colorado River Delta Biosphere Reserve (DOF 2007). The fishery primarily targets the spring spawning aggregations, in which small boats (8–9 m in length) use gillnets with a mesh size of 14.6 cm and lengths up to 293 m to harvest fish as they move to the river's mouth to spawn (Román-Rodríguez 2000; DOF 2007; Paredes et al. 2010; Erisman et al. 2012). Over the past two decades, the Gulf corvina fishery has emerged as an important economic component of the communities of El Golfo de Santa Clara, El Zanjón, and San Felipe in the northern Gulf of California (Román-Rodríguez 2000; Rodríguez-Quiroz et al. 2010). In El Golfo de Santa Clara, annual harvest increased from 3.2 tons to 1,278 tons between 1993 and 1996 and has ranged between 1,767 to 4,370 tons since 2000 (CONAPESCA 2010). The estimated average annual value of the Gulf corvina catch from 1995 to 2007 in El Golfo de Santa Clara was \$2,318,303 USD, constituting about 30% of the total value of all major fisheries in the town (Rodríguez-Quiroz et al. 2010).

The Gulf corvina is one of only a few fish species in Mexico that is regulated by an official management plan (DOF 2007), and concerns exist that the stock is overexploited and highly susceptible to a collapse (Musick et al. 2000; Rodríguez-Quiroz et al. 2010; Erisman et al. 2010a). Efforts to conserve the species and to create a sustainable fishery have been developed by government agencies in cooperation with stakeholders and regional non-governmental organizations (DOF 2005, 2007; Paredes et al. 2010). Similarly, important research on the biology and fishery of Gulf corvina has been completed (e.g., Román-Rodríguez 2000; Campoy and Román-Rodríguez 2002; Rowell et al. 2005; Erisman et al. 2012). Nevertheless, significant gaps exist related to the life history of Gulf corvina, which impede the completion of a comprehensive stock assessment necessary to regulate harvest. Such information is crucial for fisheries management, since life history traits represent key parameters used in stock assessments and comprise the core determinants of stock responses to both environmental and anthropogenic influences (King and McFarlane 2003; Shin et al. 2005).

In this study, we analyzed samples of Gulf corvina harvested by commercial fishers to characterize several life history parameters necessary for a stock assessment: population demographics, somatic and otolith growth, gonad development, and fecundity. Our specific objectives were to characterize population structure, determine growth rate by sex, estimate and validate age and size at maturity using gonadal histology and otolith annuli measurements, and describe variations in batch fecundity in relation to fish length and body mass.

## Materials and Methods

### *Collection of Specimens*

A total of 530 Gulf corvina were obtained from commercial fishers at El Golfo de Santa Clara and El Zanjón from March 2009 to May 2011. Four hundred large individuals with a mean total length (TL) of 716 mm were collected from the corvina fishery in March to April in 2009 and 2010. Given the size selectivity of the Gulf corvina gill net fishery (i.e., 14.6 cm mesh size selects for fish larger than 50 cm), an additional 130



small specimens (mean = 301 mm) were collected from the bycatch of two other commercial gill net fisheries: the commercial blue shrimp fishery (*Litopenaeus stylirostris*; 5–6 cm mesh; September–December 2009) and the bigeye croaker fishery (*Micropogonias megalops*; 6–9 cm mesh; April–May 2011) in order to obtain individuals representing younger age classes.

Meristic (e.g., 23–27 soft rays on second dorsal fin) and morphometric (e.g., presence of scaly sheath covering at least half the soft rays on the second dorsal fin) characteristics, known to be diagnostic of Gulf corvina, (Chao 2003; Robertson and Allen 2008) were used to confirm each specimen as *C. othonopterus* and to avoid inclusion of congeneric species known to inhabit the region (*C. parvipinnis*, *C. reticulatus*, and *C. xanthurus*) in the study. Total length (TL; 1 mm), total body weight (TW; 0.1 g), and sex were recorded for each fish. Otoliths were removed, dried, and stored, and gonads were removed, weighed (GW; 0.1 g), and preserved in a 10% formalin-seawater solution. Gonad-free weight (GFW) was calculated for each sample as follows:

$$\text{GFW} = \text{TW} - \text{GW}. \quad (1)$$

#### Age, Growth, and Population Structure

Sagittal otoliths (Figure 1) were removed from 492 fish (219 males and 273 females) using the method described by Craig et al. (1999) to analyze patterns related to age and growth. In the laboratory, the otolith weight (0.0001 g) and otolith radius (0.0001 mm) were measured. These data were used for age validations under the assumption that otolith weight and radius increase as fish grow and age and to verify precision of ageing methods (Cailliet et al. 1996). Otoliths were mounted on wood blocks with cyanoacrylate adhesive and a 0.5 mm dorsal-ventral cross-section was made through the focus using a Buehler-IsoMet double bladed low speed saw with diamond edged blades (Allen et al. 1995). Sections were polished using silicon carbide lapping paper and imaged while submerged in water in a black backed watch glass under a dissection scope. Each otolith was aged by two independent readers from digital images of otolith cross sections using ImageJ (Rasband 1997–2009) (Figure 1), as preliminary estimates using direct observations through the scope showed no evidence of distorting the band pattern and did not affect age estimates.

The limited seasonal availability of samples across multiple age classes prevented a marginal increment analysis to validate age determination. However, nonlinear regression was used to test for a relationship between age and otolith weight, age and otolith radius, and length and otolith radius to provide some validation for our methods of age determination and to allow for calculations of fish length directly from otolith measurements in future studies. Age and length were designated as the explanatory variables, whereas otolith weight and otolith radius were designated as the response variables. The age and length data were then fit to the following von Bertalanffy growth model (VBGM):

$$L_t = L_\infty [1 - e^{-K(t-t_0)}] \quad (2)$$

where  $L_t$  = length at age  $t$ ,  $L_\infty$  = predicted maximum length,  $K$  = growth coefficient, and  $t_0$  = theoretical age at zero length. This equation was fitted for males and females separately, and an analysis of the residual sum of squares (ARSS) was used to compare VBGM's by sex (Ratkowsky 1983; Chen et al. 1992). An ANCOVA was used to test for differences in length at age by sex.

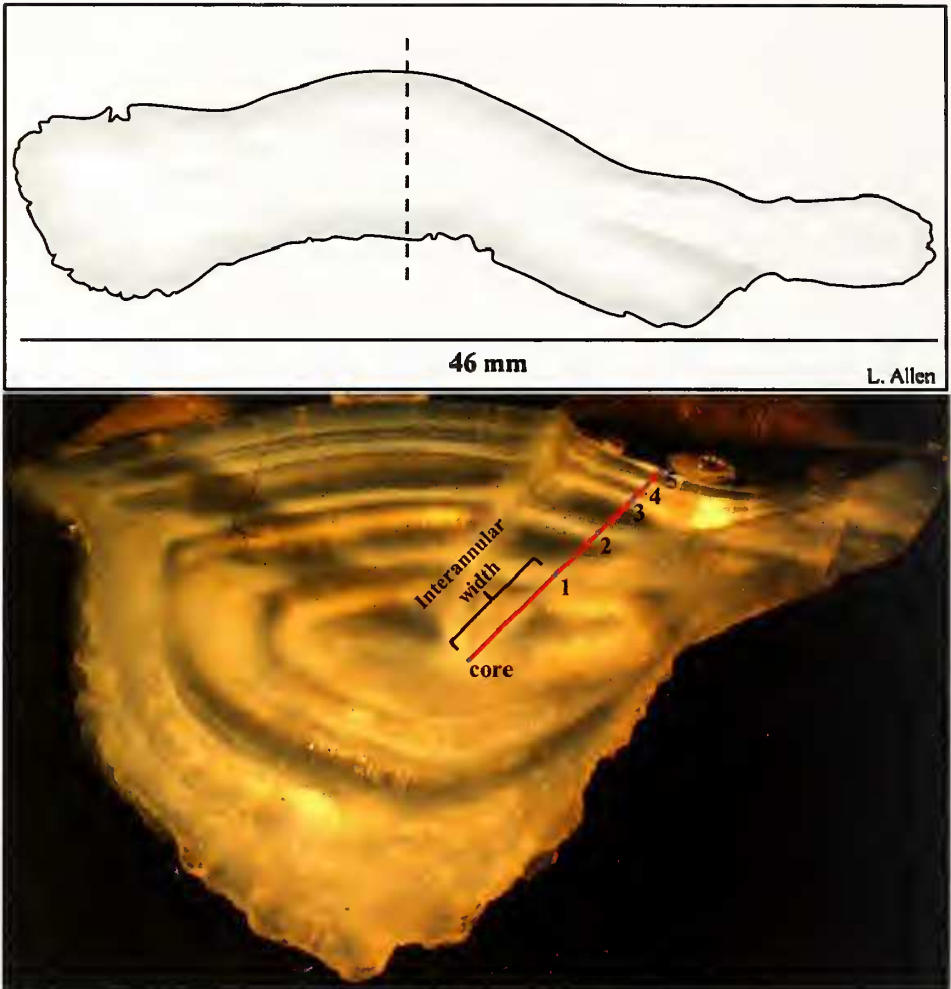


Fig. 1. Sagittal otoliths of Gulf corvina. (top) Drawing of a whole otolith from an average age 5 yr individual, where the dashed line represents where a section was taken through the focus. (bottom) Transverse section of a sagittal otolith from a 749 mm, age 5 yr individual, where numbers demarcate annuli, core is marked, and there is an example of where interannular width measurements were taken.

### *Reproductive Development and Sexual Maturity*

Standard histological techniques (Humason 1972) were used to perform microscopic examinations of gonad tissues, which provided a means to distinguish sexually mature individuals from immature individuals that had never spawned before. Briefly, preserved samples of gonad tissues were taken from the central portion of one lobe, embedded in paraffin, sectioned transversely to 5–6 micron thickness, and stained with Haematoxylin and Eosin Y. Classification of gonadal development stages followed Brown-Peterson et al. (2007). Sexually mature females were classified as containing oocytes in early to advanced (i.e., hydrated) stages of vitellogenesis, whereas sexually mature males were identified by the presence of spermatozoa within spermatocysts, lobules, or fully developed sperm ducts. Diagnosis of sexual pattern followed criteria outlined for fishes



by Sadovy and Shapiro (1987) and Sadovy De Mitcheson and Liu (2008). For both sexes, the mean size at sexual maturity ( $L_{m50}$ ) was estimated by fitting a logistic function to the proportion ( $P_m$ ) of mature fish in 20 mm ( $L_S$ ) size categories:

$$P_m = \left( 1 + e^{-r(L_{Smid} - L_{m50})} \right)^{-1} \quad (3)$$

where  $L_{Smid}$  is the midpoint of the  $L_S$  class,  $L_{m50}$  is the mean  $L_S$  at sexual maturity and  $r$  is a constant that increases in value with the steepness of the maturation schedule (Erisman et al. 2010b). The same procedure was used to estimate mean age at sexual maturity ( $A_{m50}$ ) using the proportion of mature fish in each age class.

Variations in the widths between annular bands (i.e., interannular widths) in otoliths were analyzed as another estimate of age at sexual maturity to compare with traditional estimates derived from histological analyses of gonad tissues. Rationale for this method was based on two assumptions: (1) otolith growth is generally proportional to somatic growth (Pannella 1971); (2) the ontogenetic shift to sexual maturation coincides with slowed somatic growth as energy is reallocated from growth to reproduction (Charnov et al. 2001), which is reflected in otolith growth rates. Growth rates subsequent to the first year continue to decrease as fish grow at increasingly slower rates. We hypothesize that when sexual maturity is reached, otolith growth rates slow (i.e., smaller interannular widths) to a continuous rate. One hundred and twenty fish estimated to be 5 years of age or older were randomly selected, distances between annular bands (interannular width) were measured from digital images of otolith cross sections (Figure 1), and differences between adjacent interannular widths were compared via an ANOVA with a post-hoc Tukey test.

#### *Batch Fecundity*

Batch fecundity (BF), or the number of oocytes released in a single spawning event, was estimated by the gravimetric hydrated oocyte method (Hunter et al. 1985). We analyzed 58 sexually mature females (2009,  $n = 36$  and 2010,  $n = 22$ ) collected from the corvina fishery with ovaries containing hydrated oocytes. Females with ovaries containing both hydrated oocytes and new (< 6 hr) post-ovulatory follicles (POF's) were excluded. The presence of new POF's indicates that spawning may have begun prior to sampling, which could lead to an underestimation of BF (Hunter and Macewicz 1985). Each ovary was first blotted dry with bibulous paper, and three subsamples were then removed from each the anterior, middle, and posterior region of ten ovaries (right or left was chosen at random) and weighed (0.0001g). Oocytes from each subsample were teased apart from follicles and tissue using forceps and a spatula, arranged in a single layer on a slide using water and a spatula, and imaged. Oocytes were categorized by developmental stage (Figure 2, Table 1) and enumerated using ImageJ (Rasband 1997–2009). Batch fecundity was extrapolated for each sub-sample:

$$BF = NOSS / SSW \times GW \quad (4)$$

where BF = batch fecundity, NOSS = number of oocytes in subsample, SSW = subsample weight (range = 0.0316 to 0.1420 g), and GW = gonad weight, and averaged for each region to verify that hydrated oocytes were distributed uniformly within the ovary. A one-way ANOVA was used to test for differences in BF among the three regions of the ovary. Notably, 25 ovary samples were weighed both before and after formalin preservation in order to estimate changes in gonad weight due to the preservation process and calculate a correction factor.

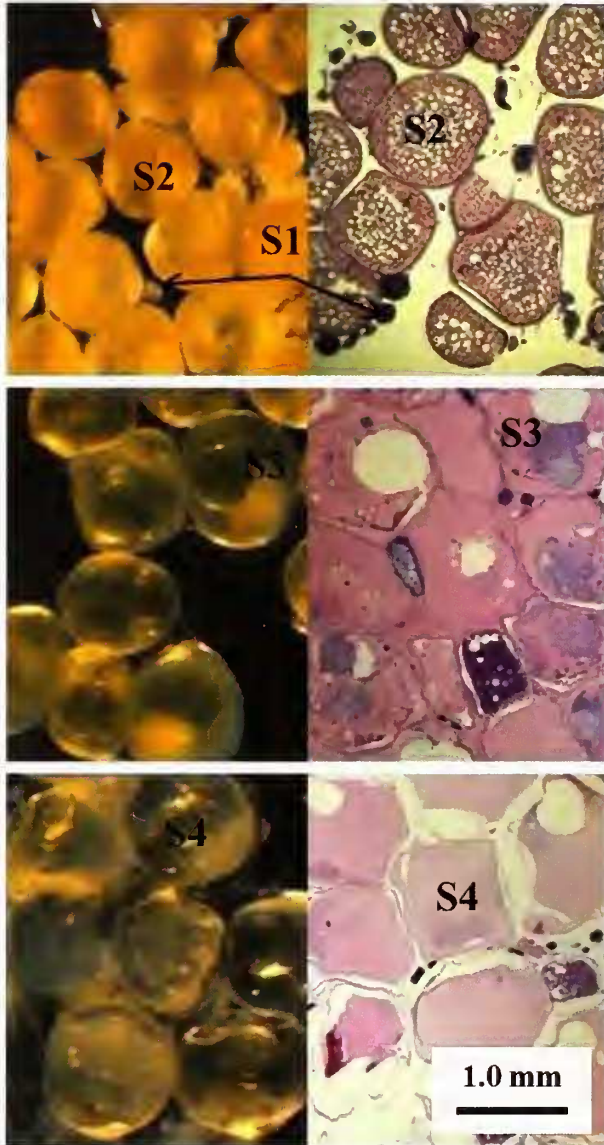


Fig. 2. Oocyte developmental stage classifications of Gulf corvina. (top) S1 = stage 1 and S2 = stage 2 under (left) dissection scope and (right) histological section. (middle) S3 = stage 3 under (left) dissection scope and (right) histological section. (bottom) S4 = stage 4 under (left) dissection scope and (right) histological section.

In order to verify the delineation of developmental stages, the vertical and horizontal diameter of up to 55 (mean = 28) oocytes per stage were measured (0.0001 mm) and averaged in 10 randomly chosen subsamples (Macewicz and Hunter 1994) using ImageJ (Rasband 1997–2009). A one-way ANOVA and post-hoc Scheffé test were used to compare oocyte diameters between stages and validate oocyte stage classification (Hunter et al. 1989). An ordinary least-squares regression was used to fit batch fecundity to GFW and length for each year and for the combined data (Hunter et al. 1985). Gonad-free weight was

Table 1. Description of developmental oocyte stages used to classify Gulf corvina oocytes in fecundity estimates and histological analyses.

Stage	Description
1	Previtellogenic to early vitellogenesis, oocyte very small (<0.7 mm), uniformly opaque, usually found with stage 3 and 4 oocytes but not as part of same batch
2	Mid to late vitellogenesis, many small oil droplets present, resulting in granular appearance, mean diameter of 0.93 mm
3	Migratory nucleus, oil droplets have coalesced into single droplet, oocyte retains spherical shape, mean diameter of 1.21 mm
4	Hydrated, oocyte becomes irregular in shape and is uniformly translucent, mean diameter of 1.16 mm

used, because hydrated oocytes significantly affect the TW of a female (Hunter et al. 1985). ANCOVA was used to compare BF at length and weight between years.

Results

Age, Growth, and Population Structure

Fish ranged in length from 145 to 1013 mm (mean =  $605 \pm 190$  mm) and age from 1 to 8 yrs (mean =  $4.5 \pm 1.6$  yrs) (Figure 3). Males ranged in length ( $\pm$  SD) from 255 to 895 mm (mean =  $636.1 \pm 145$  mm) and age from 2 to 8 yrs (mean =  $4.7 \pm 1.3$  mm), whereas females ranged in length from 215 to 1013 mm (mean =  $642 \pm 168$  mm) and age from 2 to 8 yrs (mean =  $4.9 \pm 1.4$  mm). No significant relationship was found between either mean length (ANOVA,  $df = 1$ , F-ratio = 0.367,  $p = 0.545$ ) or mean age (ANOVA,  $df = 1$ , F-ratio = 1.610,  $p = 0.205$ ) of males and females.

A significant relationship was found between otolith radius and age ( $n = 488$ ,  $p < 0.01$ ), otolith weight and age ( $n = 457$ ,  $p < 0.01$ ), and between otolith radius and length ( $n = 488$ ,  $p < 0.01$ ) (Figure 4). The VBGM equation was estimated for all samples ( $L_t = 1006[1 - e^{-0.255(t-0.616)}]$ ,  $R^2 = 0.84$ ; Figure 5), for males ( $L_t = 913[1 - e^{-0.313(t-0.644)}]$ ,  $R^2 = 0.83$ ), and females ( $L_t = 1086[1 - e^{-0.222(t-0.617)}]$ ,  $R^2 = 0.86$ ). The ARSS indicated that VBGM's did not significantly differ between sexes, (F-ratio<sub>male</sub> = 1.03,  $p_{male} = 0.40$ , F-ratio<sub>female</sub> = 1.11,  $p_{female} = 0.16$ ). The ANCOVA interaction term was not significant ( $df = 436$ , F-ratio = 0.051,  $p = 0.822$ ) and the subsequent analysis without the interaction term indicated that age was not significantly correlated to sex ( $df = 437$ , F-ratio = 3.737,  $p = 0.054$ ) but was correlated to length ( $df = 437$ , F-ratio = 1,190.720,  $p < 0.001$ ). Further examination of the residuals related to the age-at-length data showed a distinct pattern, such that samples acquired from the fishery were much larger at age than bycatch samples (Figure 5).

Reproductive Development and Sexual Maturity

Histological analyses of gonadal tissues revealed no evidence of morphological or functional hermaphroditism in Gulf corvina, indicating that the species follows a gonochoric sexual pattern (i.e., separate sexes or dioecy). Specifically, All gonadal samples consisted of either male or female structures only, and bisexual tissue (i.e., containing both male and female tissues) were not present. The minimum size and age at sexual maturity were 277 mm and 2 yrs for females and 255 mm and 2 yrs for males. The mean size ( $L_{m50}$ ) and age ( $A_{m50}$ ) at sexual maturity was 294.7 mm and 2.1 yrs for females and 267.5 mm and 2.0 yrs for males (Figure 6). Analyses of differences between adjacent interannular widths

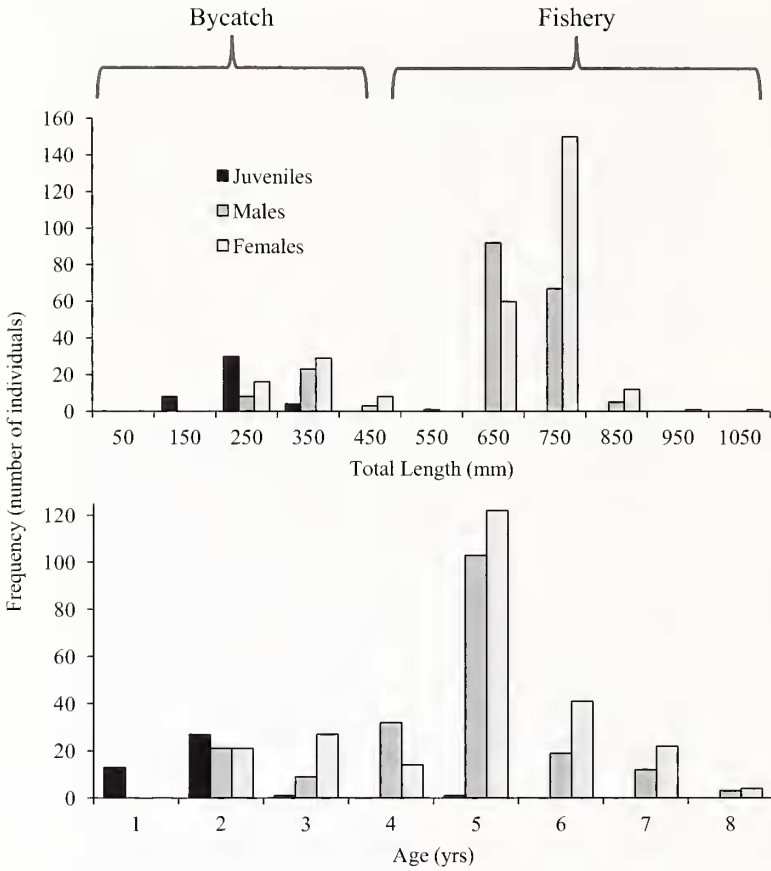


Fig. 3. Size (top) and age (bottom) distribution of Gulf corvina sampled from the targeted Gulf corvina fishery and as bycatch from other commercial fisheries from 2009 to 2011.

in otoliths indicated that at the onset of maturity adjacent interannular widths were significantly different from one another (ANOVA,  $n = 527$ ,  $df = 6, 520$ ,  $F\text{-ratio} = 86.691$ ,  $p < 0.001$ ) (Figure 7). A post-hoc Tukey test indicated that growth rates slowed to a constant rate after age two, as indicated by the comparison of the year 3 - year 4 difference to the year 4 - year 5 difference ( $p = 0.859$ ). The same results were found when males and females were analyzed separately ( $p = 0.936$  and  $p = 0.978$ , respectively).

#### *Batch Fecundity*

The smallest mature female found with hydrated oocytes was 4 yrs of age and 665 mm long. Batch fecundity estimates among the three ovarian regions (anterior, middle, and posterior) were not significantly different (ANOVA,  $n = 30$ ,  $df = 18$ ,  $F\text{-ratio} = 0.3384$ ,  $p = 0.718$ ). Therefore, the distribution of oocyte stages within an ovary were considered to be homogenous, and subsamples thereafter were taken from any region of an ovary. Mean oocyte diameters differed significantly between stages, ( $n = 762$ ,  $df = 758$ ,  $F\text{-ratio} = 1606.316$ ,  $p < 0.001$ ), and a post-hoc Scheffé test indicated that all stages were significantly different from one another ( $p < 0.001$ ) except for stage 3 and 4 oocytes ( $p = 0.053$ ) (Figure 8). Stage 1 oocytes had a mean diameter of  $0.4377 \pm 0.0085$  mm. Stage 2 oocytes had a mean diameter of  $0.9300 \pm 0.0095$  mm. Stage 3 oocytes had a mean

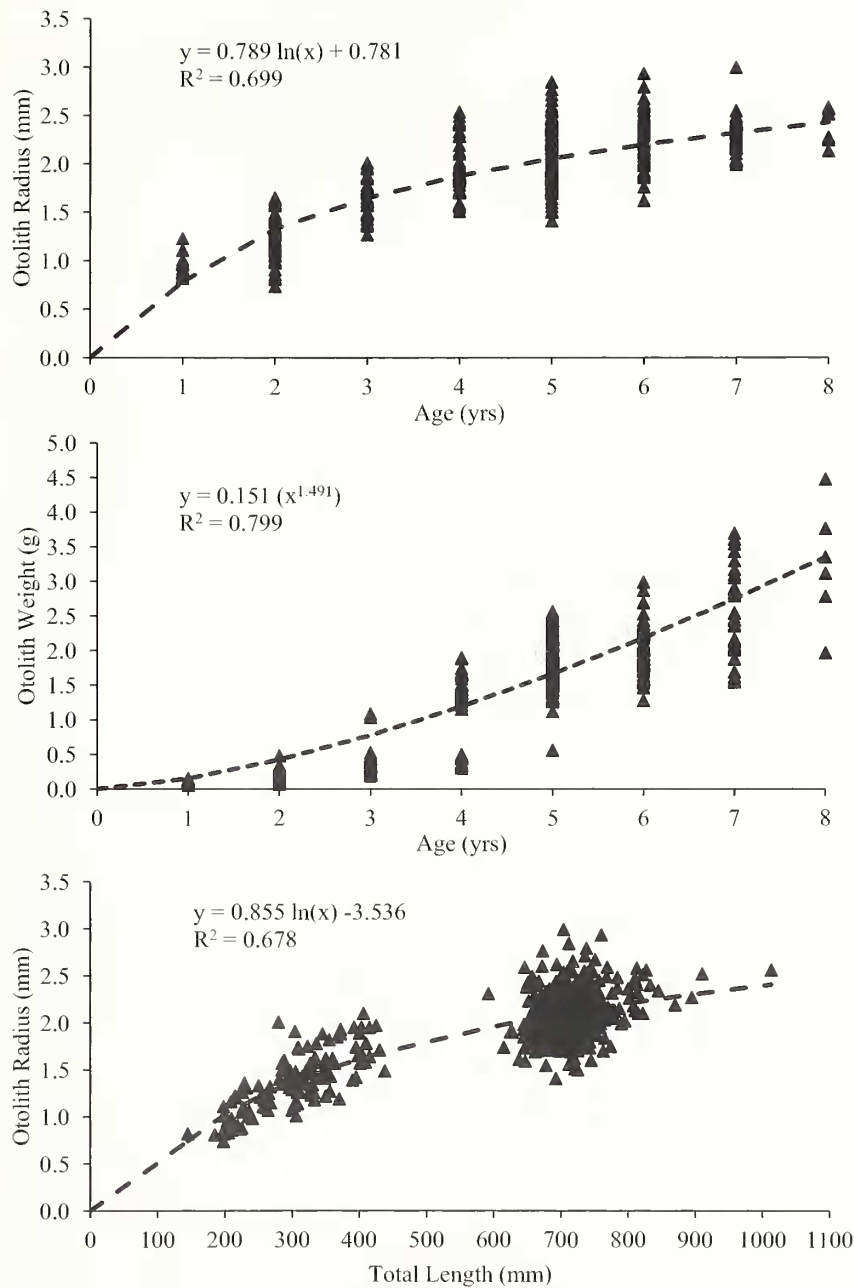


Fig. 4. Plot of nonlinear regressions of: (top) otolith radius and age (n = 488, p < 0.01); (middle) otolith weight and age (n = 457, p < 0.01); and (bottom) otolith radius and TL (n = 488, p < 0.01). Data points represent observed data while dashed lines indicate predicted values.

diameter of  $1.205 \pm 0.014$  mm, and stage 4 oocytes had a mean diameter of  $1.162 \pm 0.007$  mm. Stages 3 and 4 were both counted for estimates of batch fecundity. Estimates of BF ranged from 240,394 to 1,219,342 eggs with a mean of 684,293 eggs per spawn. In 2009 samples, a significant relationship was found between BF and both length



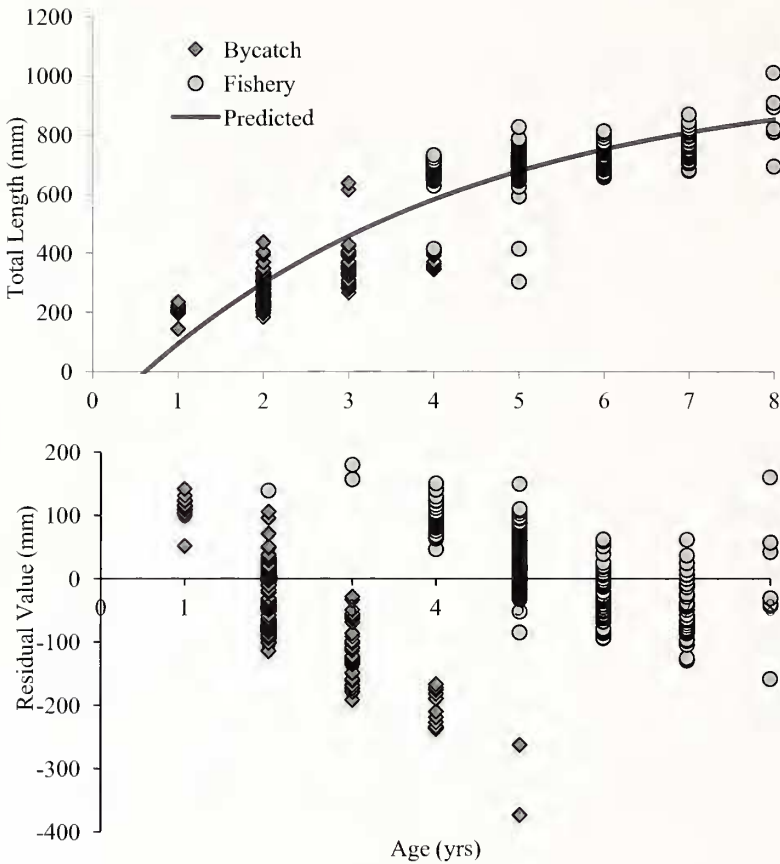


Fig. 5. (top) Age at length data by source and the von Bertalanffy growth model calculated from 492 samples of Gulf corvina. (bottom) Plot of residual values by source for length at age (observed-predicted) data included in the growth model.

(F-ratio = 26.354,  $p < 0.001$ ) and GFW (F-ratio 22.812,  $p < 0.001$ ) (Figure 9). However, in 2010, BF was not significantly related to TL (F-ratio = 1.333  $p = 0.262$ ) or GFW (F-ratio = 3.359,  $p = 0.082$ ). For the combined 2009 and 2010 data BF was again significantly dependent on both length (F-ratio = 19.044,  $p < 0.001$ ) and GFW (F-ratio = 17.102,  $p < 0.001$ ). The interaction term of the ANCOVA comparing BF and length between years was not significant ( $df = 54$ , F-ratio = 2.418,  $p = 0.126$ ) but the subsequent analysis without the interaction term indicated that BF was significantly correlated to year ( $df = 55$ , F-ratio = 34.339,  $p < 0.001$ ) and length ( $df = 55$ , F-ratio = 22.222,  $p < 0.001$ ). The interaction term of the ANCOVA comparing BF and GFW between years was not significant ( $df = 54$ , F-ratio = 2.668,  $p = 0.108$ ) but the subsequent analysis without the interaction term indicated that BF was significantly correlated to year ( $df = 55$ , F-ratio = 36.538,  $p < 0.001$ ) and GFW ( $df = 55$ , F-ratio = 22.075,  $p < 0.001$ ).

### Discussion

The collective results of this study indicate that the Gulf corvina is a fast growing sciaenid fish that attains sexual maturity at a relatively small size (200 mm) and young age (2 yrs). With respect to reproductive pattern, the species is best described as a



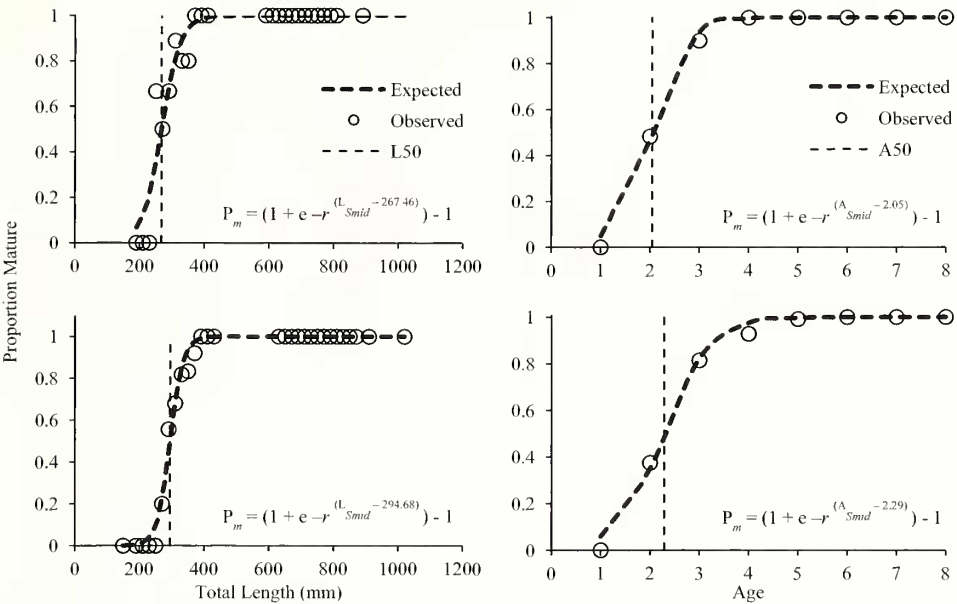


Fig. 6. Cumulative length (left) and age (right) frequency plots for male (top) and female (bottom) Gulf corvina sampled from the commercial harvest between 2009 and 2011.

gonochoric, multiple batch spawner (asynchronous oocyte development) with indeterminate annual fecundity.

Results from the growth model indicated that growth rates in males and females were similar. However, the asymptotic length ( $L_{\infty}$ ) predicted for females (1086 mm) was higher than that for males (913 mm). Of fish sampled, about 75% were greater than 600 mm and over 65% were age 5 or older. These results are likely a product of the narrow size range (c. 650–1013 mm) of fish captured by the commercial gill net fishery, which targets adult

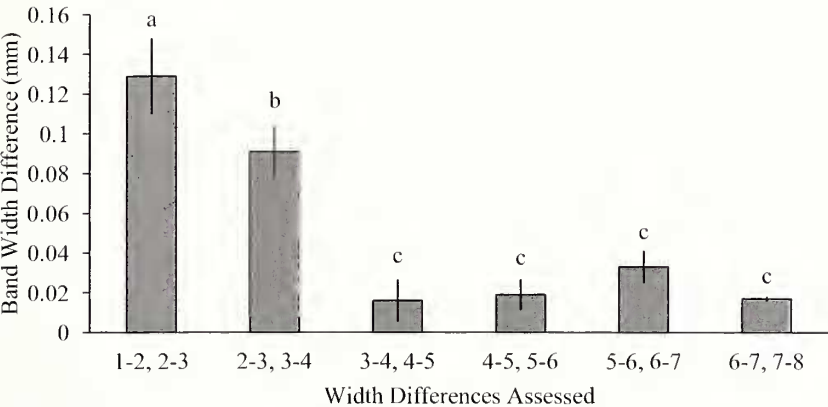


Fig. 7. Differences in adjacent interannular widths ( $\pm 1$  SE;  $n = 527$ ,  $df = 6, 520$ ,  $F$ -ratio = 86.691,  $p < 0.001$ ) in Gulf corvina; growth rate decreased at the end of the second year, indicating the onset of maturity.

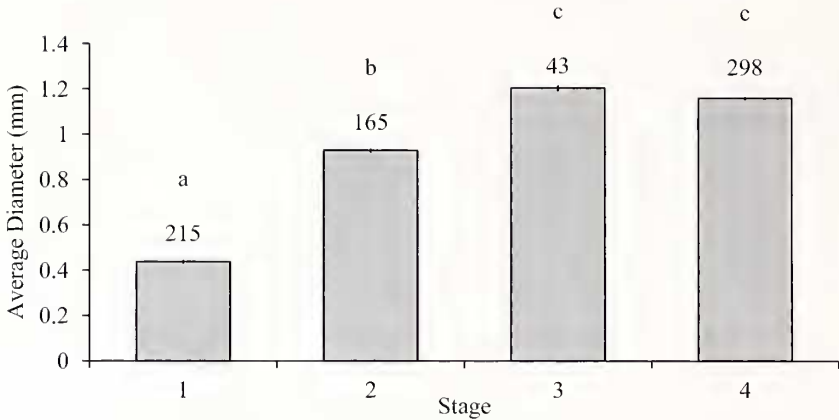


Fig. 8. Mean diameter ( $\pm$  SE) of the four developmental stages of Gulf corvina oocytes; data labels indicate sample sizes. Due to similarities in oocyte diameter, Stage 3 and 4 oocytes were combined to estimate batch fecundity.

corvina during their spawning season. Alternatively, it may be that females do reach a larger maximum length, which has been seen in congeners (e.g., *C. nebulosus*; Ihde 2000).

The overall growth pattern of Gulf corvina is characterized by rapid early life growth that slows a couple years after the onset of sexual maturity. A reduction in population size is commonly accompanied by a phenotypic response of earlier maturation and faster growth rate (Hutchings 2005; Policansky 1993). Associated benefits of early maturation include increased likelihood of reproducing before harvest and greater fitness (i.e., more chances to spawn; Hutchings and Baum 2005). However, earlier maturity may also result in reduced fecundity, decreased post-spawning survival, potentially less fit offspring, and increased probability of negative population growth (Hutchings and Baum 2005; Berkeley et al. 2004).

The large size that Gulf corvina reach in such a short time is similar to other sciaenids that co-occur in the Gulf of California (*Cynoscion xanthulus*, Riedel et al. 2007; *Totoaba macdonaldi*, Román-Rodríguez and Hammann 1997), with rapid growth early in life, reaching an average length of 279 mm by age 2 and 359 mm by age 3 (Figure 5). This is likely a result of the high productivity that characterizes the northern Gulf of California (Brusca 2010), since fish production is largely dependent on primary production (Ryther 1969; Dailey et al. 1993) and food availability tends to be positively correlated to increased growth rates of fishes (Weatherley 1972). The Gulf has extraordinarily high levels of primary productivity, due mainly to upwelling, tidal mixing, and thermohaline circulation (Alvarez-Borrego 2010; Zeitzschel 1969), which in-turn supports some of the world's largest sardine, anchovy, and shrimp populations and fisheries (Alvarez-Borrego 2010), all of which are food for Gulf corvina (Román-Rodríguez 2000). Similarly, positive correlations between growth rate and water temperature are common in sciaenids and many other marine fishes (Lankford and Targett 1994; Brander 1995; Williams et al. 2007), and sea surface temperatures in the upper Gulf of California average 24° C and exceed 32° C during the summer months.

Our initial estimates of the growth parameter ( $k$ ) of 0.255/yr appeared relatively low for a species with a fast growth rate and a maximum age of 8 yrs, although similar growth rates have been reported in populations of *Cynoscion* species (Shepherd and Grimes 1983; Riedel et al. 2007; Colura et al. 1994). In addition, we found clear differences in the

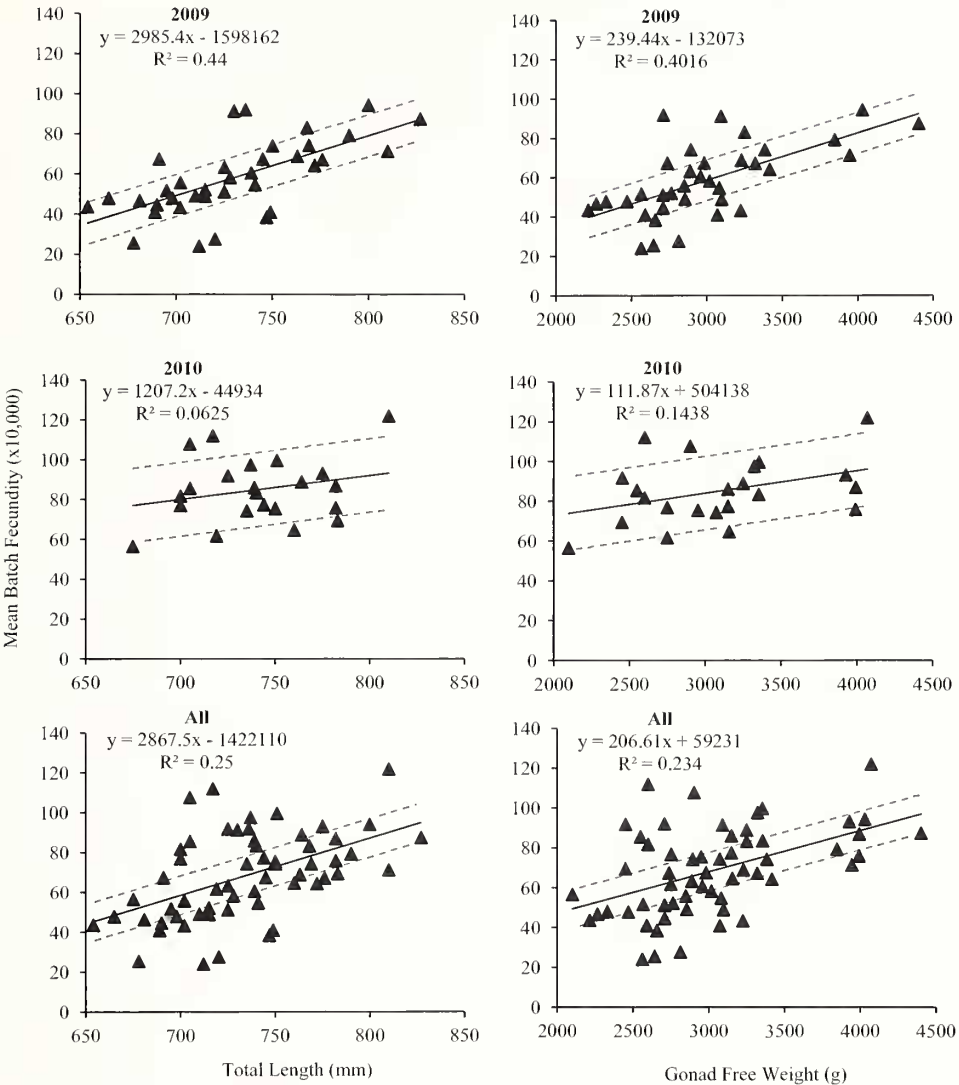


Fig. 9. (left) Ordinary least-squares regressions of batch fecundity and total length for 2009, 2010, and grouped for Gulf corvina. (right) Ordinary least-squares regressions of batch fecundity and gonad-free body weight for 2009, 2010, and grouped for Gulf corvina. For each graph, the solid black line represents the line of best fit, and the red dashed lines indicate 95% confidence intervals.

pattern of residuals between the fishery and bycatch data, which indicated that fish sampled from the targeted corvina fishery tended to be larger at age than those collected as bycatch from other fisheries. These dissimilarities may reflect that these samples were collected from two subpopulations of Gulf corvina with different growth strategies. For example, the targeted Gulf corvina fishery operates in the estuaries of the Colorado River Delta, whereas the shrimp fishery that provided most of our smaller samples operates mainly at offshore locations and habitats 50 km or more to the south or southeast (Rodriguez-Quiroz et al. 2010). Variations in growth rate were reported among populations of the weakfish (*Cynoscion regalis*) in the Middle Atlantic Bight and were

attributed to varying allocations of energy to somatic growth in relation to environmental and migratory requirements and the availability of food items in each habitat (Shephard and Grimes 1983). Alternatively, such differences may simply be a product of the size selectivity of each fishery. Shrimp and croaker fisheries use 6.5–8.5 cm mesh gill nets that are deployed as drift nets and tend to land corvina less than 50 cm long. Conversely, the Gulf corvina fishery uses 14.6 cm mesh gill nets deployed in a similar fashion to purse seines (fish are encircled; see Erisman et al. 2012), and selectively removes fishes 50 cm or greater in length. Under this scenario, fish harvested by the corvina fishery may be larger than average size-at-age, whereas those landed as bycatch may be average or below average in size.

Regardless of the cause, the two sources of samples included in the age and growth study produced a VBGM with significant uncertainty, and one that may not accurately reflect the average growth rate of the species or incorporate possible variations in growth rate by location. It is important to produce unbiased life history parameters that accurately reflect the stock or population, as these feed directly into fisheries assessments (e.g., estimates of natural mortality and exploitation rates; virtual population models, calculations of sustainable yield). Even subtle changes to these life history parameters may result in significant changes in model outputs and conclusions (Chen et al. 1992; Van Den Avyle and Hayward 1999), which in turn, can result in highly different perceptions among resource managers with respect to the health or condition of the stock and changes in harvest regulations. The systematic collection of representative length samples should be implemented by a scientifically designed, fishery-independent survey that utilizes nets with a variety of mesh sizes during several periods of the year and at several locations. Results from this type of survey would provide a better representation of the overall length and age structure of the population (Van Den Avyle and Hayward 1999).

Histological analyses of male and female gonad tissues indicate that Gulf corvina reaches sexual maturity at approximately 2 yrs of age. In addition, differences in adjacent otolith growth increment widths indicate that after age two, otolith growth slows significantly, and all subsequent ages are characterized by similar slow growth rates. Tight correlation between fish size and otolith size (radius, length or weight) suggest that otolith growth rates are an appropriate proxy for estimating fish growth rates; however these relationships are nonlinear and length backcalculations must account for this (Campana and Jones 1992; Pannella 1971; Secor and Dean 1989). Measurements of otolith length, radius or width are often used in fisheries as corollaries to fish size and to back calculate fish age. While in some more fine resolution studies, using these proxies may not be appropriate, as demonstrated by Mosegaard et al. (1988) in 8–108 day experiments; however, in a lower resolution context (years vs. days or months) otolith growth appears to scale with somatic growth sufficiently to make estimates. In this study we find that Gulf corvina otolith size and weight are correlated to fish size, and otolith growth (radius) is highly representative of fish growth curves. The onset of maturity as seen in the slowing of otolith growth rates lagged that of histological analyses by a couple years. This suggests that for fish with life history characteristics similar to Gulf corvina, analyzing otoliths growth rates may provide additional archival information on age at maturity.

Fish ranging from 650 to 750 mm and 5 to 6 yrs of age were the most common in the fishery, with few fish larger than 800 mm or 8 yrs of age captured by the gillnet fishery. It is uncertain whether Gulf corvina reach lengths and ages greater than those harvested by the fishery or whether the fishery harvests the largest individuals of this species. Thus,